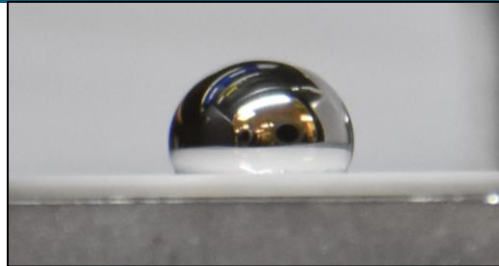


# Advancing Sodium Batteries Through the DOE Office of Electricity



*PRESENTED BY*

Erik D. Spoerke, Ph.D.

DOE Office of Electricity Peer Review 2020

This work at Sandia National Laboratories is supported by Dr. Imre Gyuk through the U.S. Department of Energy Office of Electricity.



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SAND No.: SAND2020-10397 C

# Are All Sodium Batteries The Same? Na!



Sodium batteries...

- Take advantage of globally abundant sodium...
  - 6th most abundant element in Earth's crust and 4<sup>th</sup> most abundant in the oceans.
  - 5X the annual production of aluminum
- Offer potential for safe, versatile, cost-effective energy storage
  - Grid-scale and backup power
  - Portable or vehicle storage



Sodium Metal

There are a number of sodium battery technologies in development or production:

## 1. Molten sodium (Na) batteries

A. Sodium Sulfur (NaS)

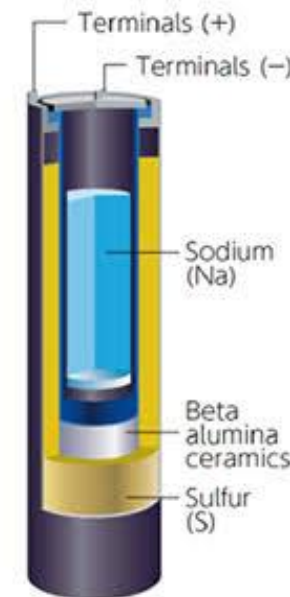
B. Sodium Metal Halide (Traditional ZEBRA Batteries)

- ✓ *New ZEBRA Batteries (Ni-free, operate below 200°C) - PNNL*
- ✓ *Low Temperature (~100°C) Na-NaI Batteries - SNL*

## 2. Sodium Ion Batteries (NaIBs) - PNNL, ORNL

## 3. Solid State Sodium Batteries (SSSBs)

## 4. Sodium Air Batteries (Na-O<sub>2</sub>)



- Sodium Image from Dnn87 at English Wikipedia. - Transferred from en.wikipedia to Commons., CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=3831512>
- NaS battery schematic from NGK Insulators.

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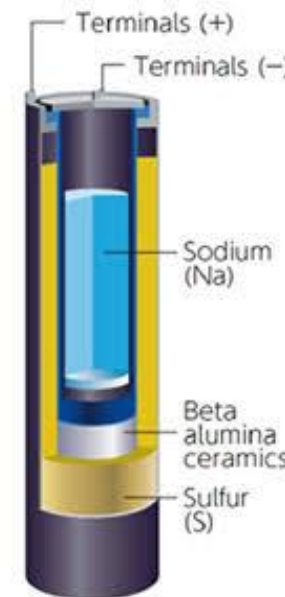
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DOE OE Research Focus

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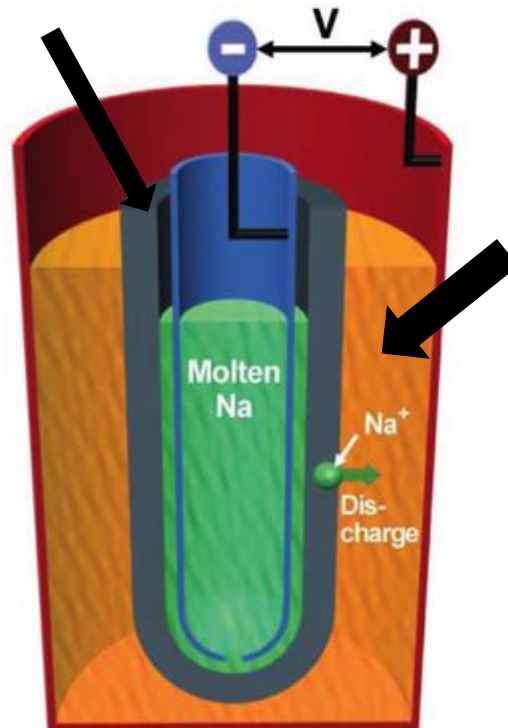
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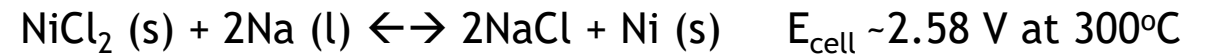
Ion Conducting  
Ceramic Separator



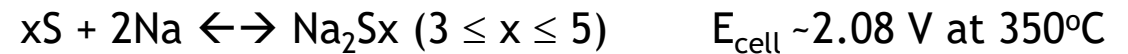
“Molten Catholyte”

- Sulfur
- M-Halide Salts

## Na-NiCl<sub>2</sub>



## Na-S



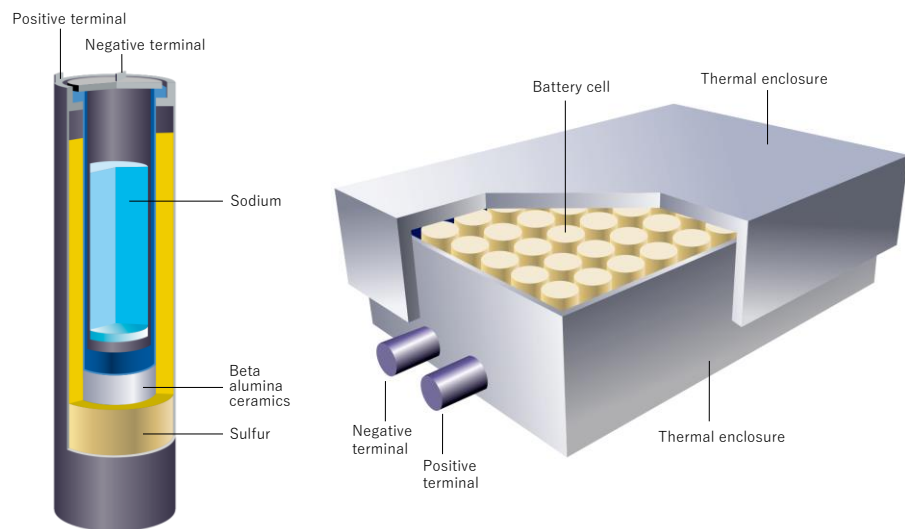
	Practical Energy Density (Wh/L )	Expected Cycle Life (cycles at 80% DOD )	Expected Lifetime (years)	Operating Temperature (°C)	Suitable Ambient Temperature (°C)	Discharge Duration (at rated power)	Round Trip Efficiency
NaS	300-400	4,000-4,500	15	300-350	-20 to + 40	6-7 hours	80%
Na-NiCl <sub>2</sub>	150-190	3,500-4,500	20	270-300	-20 to +60	2-4 hours	80-85%

- Na-S takes advantage of low cost materials, but introduces some safety concerns.
- Na-NiCl<sub>2</sub> is a safer chemistry, but high cost of Ni is a challenge.

# Molten Sodium Battery Deployment: NaS



*NGK Insulators, Ltd (Japan) has developed a successful NaS battery system with long lifetime and a strong safety record.*



50 MW system  
supporting a solar  
array in Fukuoka,  
Kyusu, Japan.

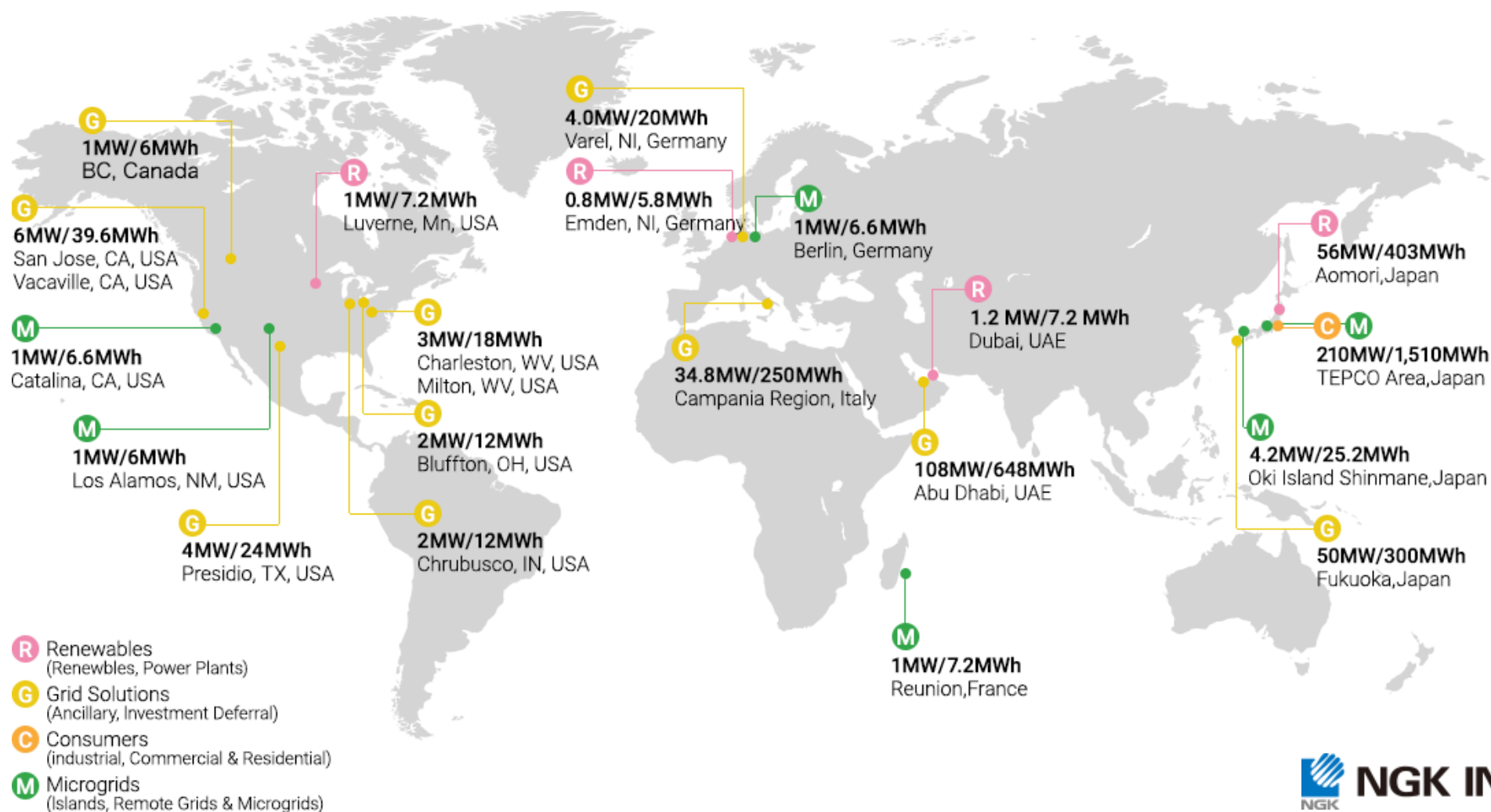
Voltage	2V
Energy density	367 Wh/l 222 Wh/kg
Power density	36 W/kg
C-rate	1 / 6 = 0.17
Optimal temperature range	300 - 340 °C
Maximal temperature range	290 - 360 °C
Life time	4500 cycles 15 years
Discharge Duration	4-6 hours



## Molten Sodium Battery Deployment: NaS



NGK has deployed 580 MW/4 GWh of storage in over 200 sites around the world.



FZSoNick (Italy, Switzerland, USA) is actively deploying ZEBRA batteries for use in

- Energy Backup (48-110V)
- Sustainable Mobility (300-700V)
- Energy Storage (48V and 620V)

## FZSoNick (Na-NiCl<sub>2</sub>) Batteries

- ~300°C operation, no cooling required
- 2-4 hour energy applications
- Operational from -20°C to +60°C
- 20 year design life (3500-4500 cycles)
- Environmentally friendly and *recyclable*
- “No maintenance”
- Passed UL9540A: "Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems"



48 V (200Ah)  
module



620V module



620 V 90 kWh (25kW)



620 V 1.4 MWh (400 kW)

# Molten Sodium Battery Deployment: Na-NiCl<sub>2</sub> (ZEBRA)



Intended for On-Grid, Microgrid, and Off-Grid Applications

- Power Quality
- Frequency Regulation
- Load Shifting
- Peak Shaving
- Backup Power
- Renewable Resource Integration

**>130 MWh of backup power and grid-storage installed globally**

## Energy Backup

1. Telecom



2. Railway



3. UPS



## Sustainable Mobility

1. Light commercial vehicle



2. Bus



3. Mining



## Energy Storage

1. Off grid application



2. RE\* generator (residential/industrial)



3. Transmission and distribution service operator





## Upcoming ZEBRA Battery Deployment?



The Chilwee Group (China) recently acquired GE's Durathon technology and has announced plans to begin manufacturing these batteries as part of a more comprehensive battery manufacturing effort.



The Fraunhofer Institute for Ceramic Technologies and Systems (IKTS) in Germany has also developed their own Na-NiCl<sub>2</sub> battery platform (Cerenergy®) for grid-based energy storage. They advertise an effort to adapt the cell design and improve materials chemistry in these systems to reduce cost, but at present, these systems are not widely deployed.

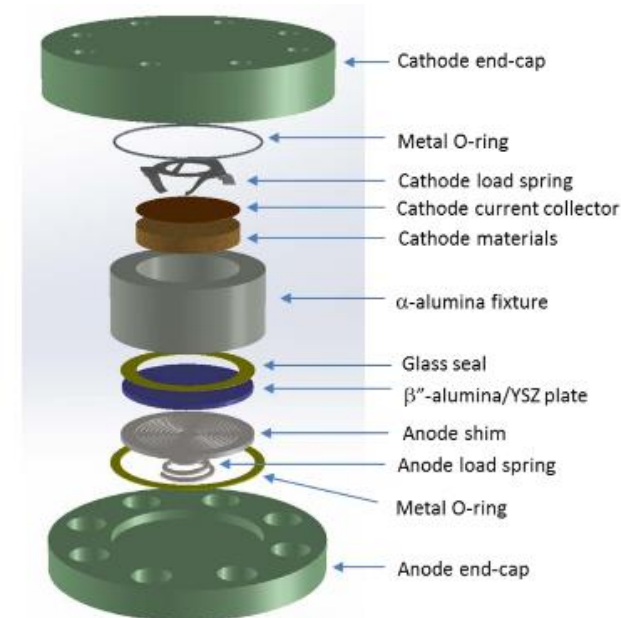
# Lowering Battery Operating Temperature to Drive Down Cost



Our Collective OE Objective: A safe, reliable, molten Na-based that eliminates costly reagents (e.g., Ni) and operates at reduced temperatures (below 200°C).

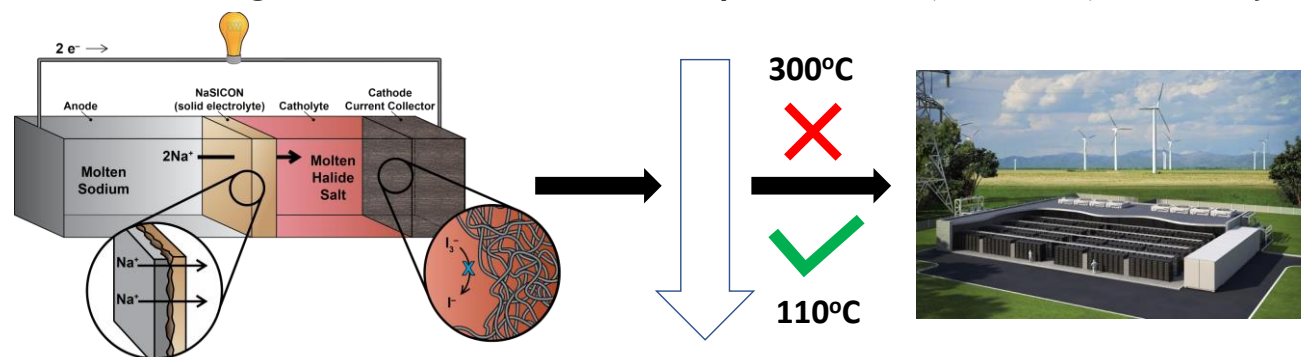
- Improved Lifetime
  - Reduced material degradation
  - Decreased reagent volatility
  - Fewer side reactions
- Lower material cost and processing
  - Seals
  - Wiring!
  - Cell body
  - Polymer components?
- Simplified heat management costs
  - Operation
  - Freeze-Thaw

PNNL intermediate temperature planar Na-MH battery design.



Li, G, et al. *Nature Commun.* 2016, 7, 10683.

SNL design for Na-NaI low temperature (~100°C) battery



## Looking Forward: Long Duration Energy Storage (LDES)



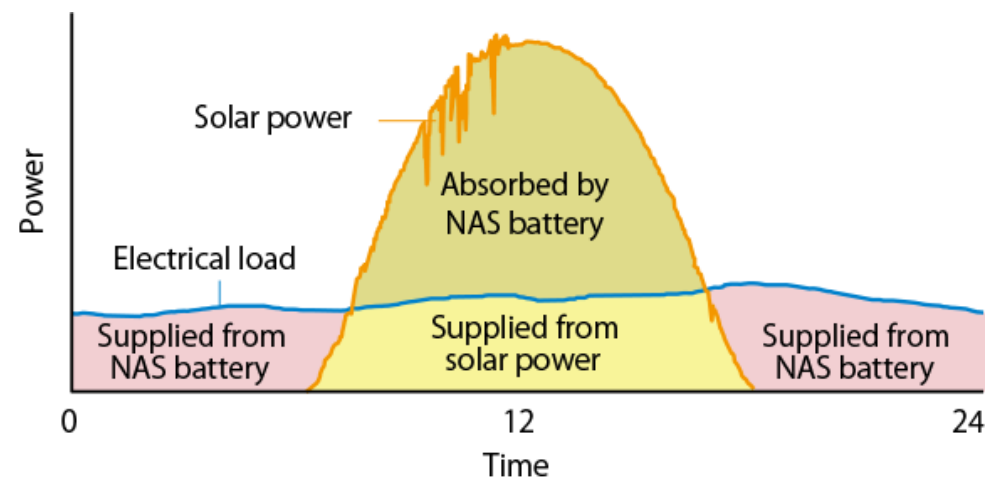
Long Duration storage is an emerging area of battery development and can mean a number of things, ranging from discharge durations greater than 10 hours to seasonal storage.

LDES may involve hybrid technologies that combine multiple storage systems (e.g., Thermal + Electrochemical) or storage combined with renewable generation (e.g., Solar + Storage).

*There are opportunities for Sodium batteries to impact “Long Duration” storage!  
(Stay tuned for LDES workshop later this fall!)*

### Example 1: 18 hour NGK NaS Batteries.

- Effective solar power on microgrids requires 14-18 hours of discharge time to fully shift solar energy.
- NGK’s Na-S batteries are typically rated for 6 hours, at full output rating, but run at 1/3 rated output, they will provide electricity for 18 hours!

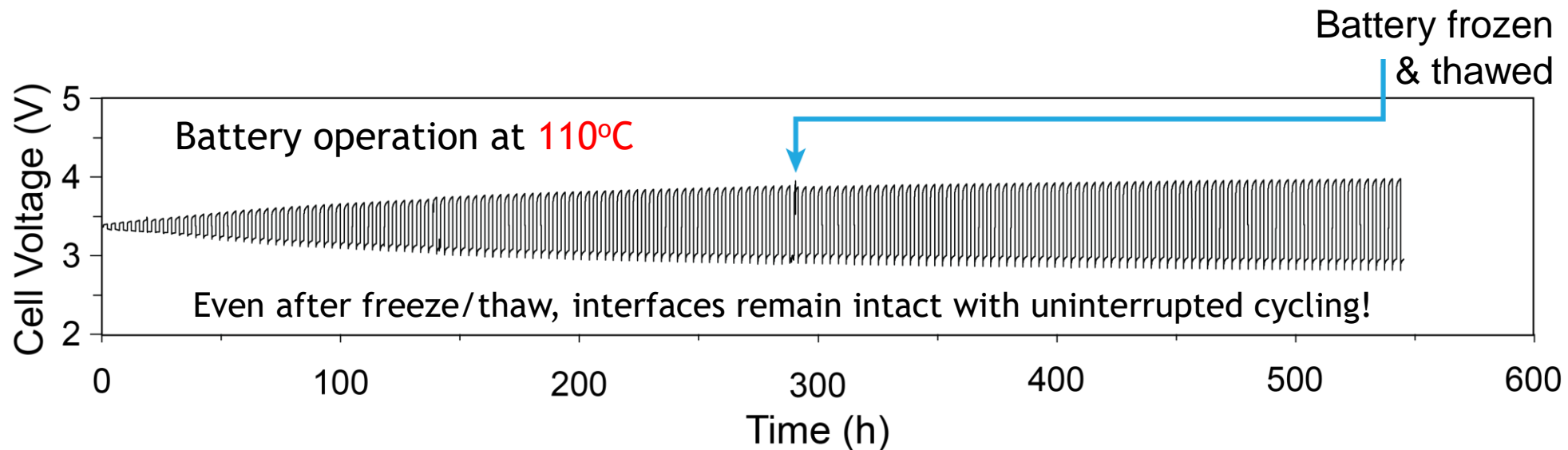


## Looking Forward: Long Duration Energy Storage



Example 2: Low temperature “freezable” batteries for seasonal energy shifting.

- At FY19 DOE peer review, the SNL team showed that low temperature molten salt batteries was cooled until “frozen”, and then restarted with no interruption of electrochemical cycling behavior.
- This approach could be used to store seasonal renewable energy (e.g., summer solar), then frozen until needed at a (much) later date (e.g., winter).
- The low temperature operation makes this turn-around shorter and less energy intensive.



Upcoming talk by Guoshon Li: “Perspectives and strategies of developing long duration and seasonal energy storage technologies for improving grid resiliency and reliability”

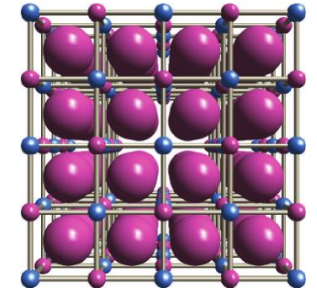




While not yet commercially mature, several types of NaIBs are in development or early production.

## Prussian blue analogs (PBAs)

- Utilize ferric ferrocyanide salts as electroactive materials (mostly cathodes)
- Natron Energy is developing NaIBs with PBAs aimed at 8kW units for data server backup power.



Y. Moritomo, *Adv. Cond. Matt. Phys.* (2013) 539620.

## Li-Ion “Analog” - possibly manufacturable on Li-ion production lines?

- Faradion (UK) - produced over 50kWh of prototypes with sodium-nickel layer oxide cathodes since 2011).
- HiNa (China) - Over 10,000 prototypes, currently demonstrating 100kWh prototype with anthracite anode and Co,Ni-Free layered metal oxide cathode.

## “Salt-water batteries”

- Carbon-titanium phosphate composite Anode, sodium perchlorate aqueous electrolyte, manganese oxide cathode.
- Aquion - MW scale deployment before restructuring in 2017. Current status?
- BlueSky Energy (Austria) - “Greenrock” Saltwater Battery
  - 5kWh-30kWh systems for renewables, emergency power, off-grid solutions
  - 15 year lifespan, 5,000 cycles, -5°C to +50°C operation, safe and environmentally friendly



## On to the Main Show: Presentations



Institution	Title	Authors
Sandia National Laboratories	Low Temperature Molten Sodium Batteries	<u>Leo J. Small</u> , Martha M. Gross, Stephen J. Percival, Rose Y. Lee, Amanda S. Peretti, Ryan C. Hill, Yang-Tse Cheng, Erik D. Spoeke
University of Kentucky	Multi-scale characterization of the Structure and Mechanical Properties of Sodium Ion Conductors	<u>Y.T. Cheng</u> , Ryan C. Hill, Amanda Peretti, Leo Small, and Erik D. Spoeke
Pacific Northwest National Laboratory	Advanced Na-ion battery: Progress towards Co-free cathodes	<u>Biwei Xiao</u> , Fredrick Omenya, Hyungkyu Han, David Reed, Vincent L. Sprenkle and Xiaolin Li
Pacific Northwest National Laboratory	Advanced intermediate temperature sodium-metal halide (Na-MH) batteries for grid storage application	Miller Li, Jeff Bonnett, Evgueni Polikarpov, David Reed, Vince Sprenkle, and <u>Guosheng Li</u>
Pacific Northwest National Laboratory	Perspectives and strategies of developing long duration and seasonal energy storage technologies for improving grid resiliency and reliability	Miller Li, Aaron Hollas, Daiwon Choi, Xiaolin Li, David Reed, Vince Sprenkle, and <u>Guosheng Li</u>
Oak Ridge National Laboratory	Engineering Routes Towards Synthesis and Performance of Layered Oxide Cathode Materials for Sodium-ion Batteries	Mengya Li, Yaocai Bai, Rachid Essehli, Ruhul Amin, Ilias Belharouak, Jianlin Li, <u>David L. Wood III</u>

## Please Don't Miss: Posters



Institution	Title	Authors
Sandia National Laboratories	Electrochemistry of the NaI-AlBr <sub>3</sub> Low Temperature Molten Salt System: Implications for Sodium Battery Performance	<u>Stephen J. Percival</u> , Rose Y. Lee, Martha M. Gross, Amanda S. Peretti, Erik D. Spoerke, Leo J. Small
Sandia National Laboratories	Development of High-Performance Low-Temperature Molten Sodium Batteries	<u>Martha M. Gross</u> , Stephen J. Percival, Amanda S. Peretti, Joshua Lamb, Erik D. Spoerke, Leo J. Small
Sandia National Laboratories	Solid State Separator Development for Sodium Batteries	<u>Erik D. Spoerke</u> , Amanda S. Peretti, Martha. M. Gross, Stephen J. Percival, Ryan Hill, Yang-Tse Cheng, and Leo J. Small
University of Kentucky	Mechanical and Microstructural characterization of Montmorillonite Sodium Ion Conductors	<u>Ryan C. Hill</u> , Amanda Peretti, Leo Small, Erik D. Spoerke, Yang-Tse Cheng
Pacific Northwest National Laboratory	Advanced Na-ion battery: Scaling up of Na-ion battery materials and large cells	<u>Fredrick Omenya</u> , Biwei Xiao, Hyungkyu Han, David Reed, Vincent L. Sprenkle and Xiaolin Li
Penn State University	Development of sulfide based solid state electrolyte for Na-ion batteries	<u>Donghai Wang</u>